




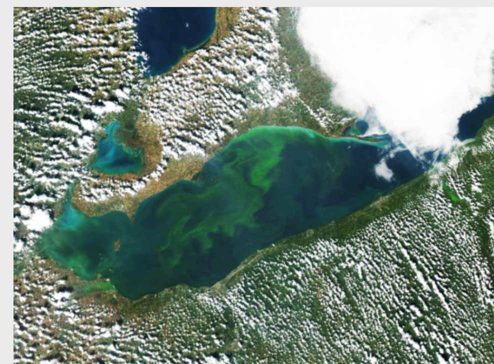


Management, Mitigation and Remediation of Cyanobacteria Harmful Algae Waterblooms (CyanoHABs)

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CyanoHABs are problematic

- Cyanobacteria, or blue-green algae, are ancient microbes responsible for aerobic photosynthesis and production of the earth's oxygen. They range from thermal hot springs to high altitude rocky terrain. Due to improper and over development of water resources, especially nutrient enrichment, cyanobacteria proliferate or "bloom" forming dense growths. These blooms disturb food chains, contaminate water treatment systems, and produce potent toxins that sicken and kill wild and domestic animals and humans.

  Humans have responded with physical, biological and chemical controls. By themselves, these are temporary, do not involve a multilevel approach and do not address the root cause of cyanoHABs, i.e. nutrient enrichment (eutrophication), inadequate design and management of water supplies and ineffective management of watersheds that supply those water bodies. Multilevel remediation is the best way to achieve real success for control of cyanoHABs.

Approaches involve the 3-M's

1) Monitoring

2) Management

3) Mitigation

Toward the ultimate goal of- Remediation

Approach Level 1:

Monitoring = Remote Observation, Sampling, Taxonomy, Cyanotoxin Detection-All Inform the Process of Setting HAB:

1) Advisory Guidance

2) Management

3) Mitigation

Approach Level 2 and 3:

Management:

Use of a Risk-Management Framework to minimize the cyanoHAB event

Mitigation:

Attempt to prevent cyanoHAB effects:

Choice of proper point for water abstraction
Choice of optimum water treatment techniques
Choice of proper algicide

***In reality these methods serve to minimize bloom effects. Only true prevention involves maintaining high water quality where they already exist. Failing that, prevention involves remediation.**

Lake/Reservoir Management Tools

Physical controls: Manipulation of the intake location or depth, aerators (destratification), mechanical mixers (long distance circulation) and barriers (sand, carbon).

- Biological controls
  - ✓ **manipulation of the lake ecology to favor cyanobacteria grazers (top-down) and increased competition for nutrients (bottom-up)**
- Chemical controls
  - ✓ **phosphorus treatments (e.g. lime, aluminum sulfate, ferric chloride, lanthanum and clay particles)** Used to both bind nutrients and flocculate cells.
  - ✓ **algaecides (e.g.,** copper-sulfate, hydrogen peroxide, potassium permanganate, herbicides)

Caution: applying algaecides during a large bloom with toxin-producing species will cause the cells to rupture and release the toxins.

Current ref: Solutions for Managing Cyanobacterial Blooms: A scientific summary for policy makers. 2019. M.A. Burford et al. IOC/UNESCO, Paris (IOC/INF-1382).

Drinking Water Treatment Methods

- Treatment to remove intracellular cells and algal toxins
  - Conventional treatment
    - Filtration (sand, soil)
    - Flocculation (alum, clays, lanthanum)
- Treatment to remove extracellular algal toxins
  - Oxidation (ozone, chlorine)
  - Physical removal (adsorption and absorption; carbon)
  - Biologically active filters
- Newer technologies
  - Dissolved Air Flotation (cells and intracellular toxins)
  - Low pressure membrane filtration
  - High pressure filtration
  - Reverse Osmosis (RO)

Moving beyond Management and Mitigation

- While mitigation implies removing cyanoHABs from a water body and preventing their occurrence, it relies on the management tool approach.
- Unless we are willing to make major efforts towards, protecting and improving watersheds, and address global warming the best we can do is bloom management.
- Remediation utilizes management/mitigation techniques but is a more multilevel approach. An approach that returns the water body to pre-cyanoHAB state. Involves:
- 1) Understanding the basic morphometry (using sonar scan), biology and chemistry of the water body in question.

  (informs the placement of the air/water flow system)

  2) Use air/water flow (micro porous ceramic diffusers), complemented with bioaugmentation* that together will remove lake sediments and shift the phytoplankton population to diatoms and green algae. These treatments increase water volume, move nutrients into food webs that are beneficial, allow competition by beneficial algae to outcompete harmful cyanobacteria and exposes hard sediments that do not encourage growth of aquatic plants.

*Bioaugmentation: includes use of bacteria and native enzymes to increase the sediment decomposition plus selective minerals and micronutrients to shift phytoplankton toward diatoms and green algae. In the case of SIS Bio this uses two products: enzyme mix= Clean and Clear (mercaptases, amylases, proteases, lipases and water) and a nutrient mix= Bio Booster LQ (Fe, Mn, Co, Mo, Ca, Mg, Zn, Si, B, Cu).

Example 1: LAKE PEEKSKILL

Lake Peekskill, Putnam Valley, NY

- **60 acres**
- **Max depth 26 feet**
- **Average depth 12 feet**
- **Volume 718 acre-feet**

Closed to public because of CyanoHABs for many years

Only open for 3 days in 2018

Remediation commissioned on June 20th 2018 when lake was already closed due to CyanoHABs

As of Oct. 2019:
Sediment reduction 49,000 cubic yards

Sediment P reduction 11%

No confirmed CyanoHAB incident in 2019

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1) Micro ac RADOR
units, 1 x 12.7hp compressor

2) Enzyme & nutrient bioaugmentation treatments

Lake Peekskill NY

Date of commissioning

Dissolved Oxygen & Stratification

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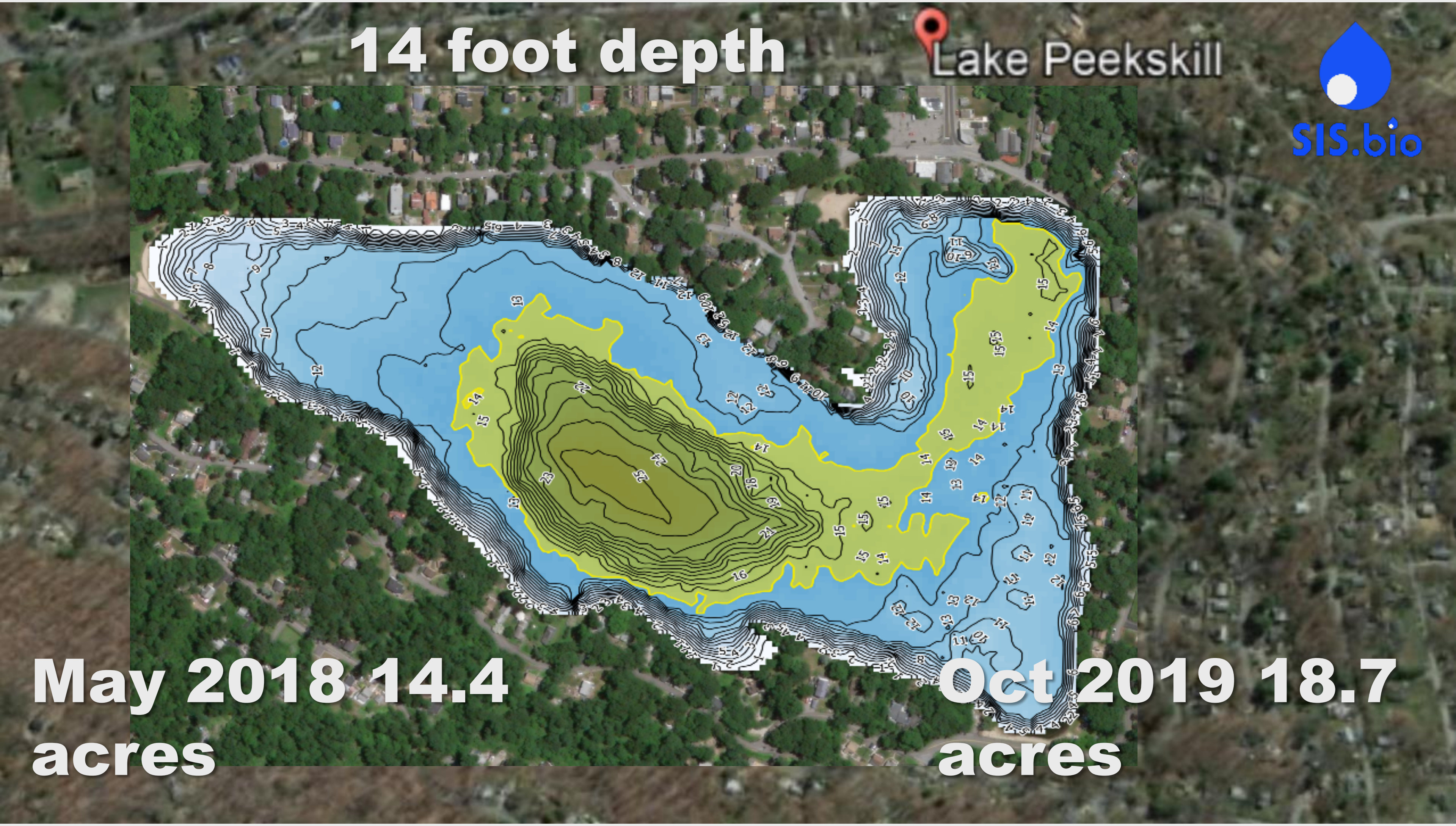
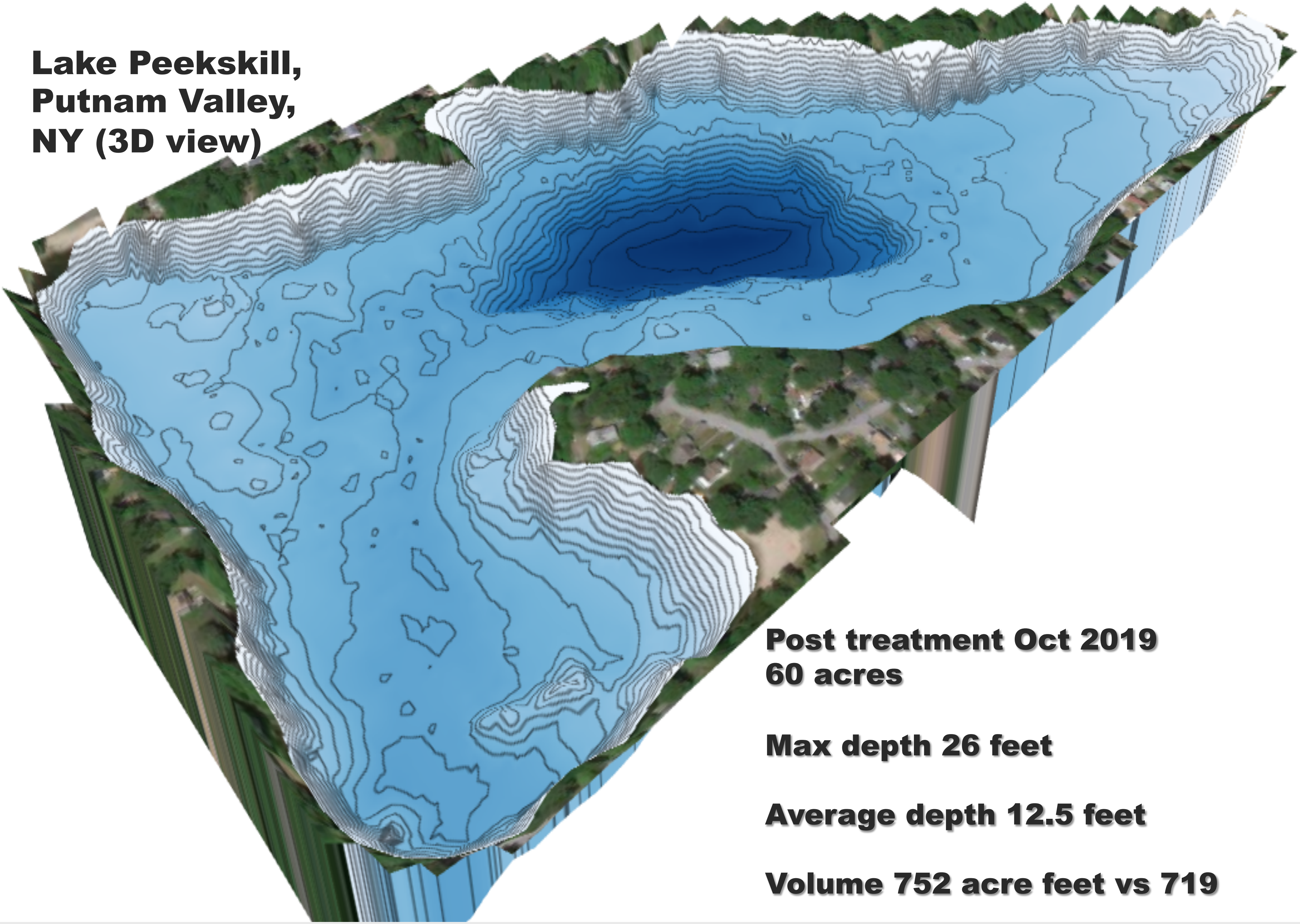
Date	6/20/18	6/20/18	6/20/18	6/20/18
Location	S1	S2	S3	S4
Depth				
1	9.3	9.13	9.14	9.31
3	9.11	9.24	9.18	9.05
5	9.12	9.11	9	9.12
7	9.2	9.69	9.71	9.27
9	8.85	9.34	9.06	9.02
11		9.49	9.01	9
13		9.52	7.08	
15		3.91		
17		0.53		
19		0.08		
21		0.01		
23				

Dissolved Oxygen mg/l

Destratified & Reoxygenated


14 foot depth
Lake Peekskill
SIS.bio
May 2018 14.4 acres
Oct 2019 18.7 acres

Lake Peekskill, Putnam Valley, NY (3D view)



Post treatment Oct 2019
60 acres

Max depth 26 feet

Average depth 12.5 feet

Volume 752 acre feet vs 719

Lake Peekskill, Putnam New York

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Waterbody Size: 60.11 acres

report link

Data Collector	Survey Size	Offset Information
Brian Kling	Area: 60.00 acres	See Below
	Percent: 99.82% of waterbody	

Data Collection Date

32.27 acre feet = 52,062 cubic yards

A dump truck holds 15 cubic yards

52,062 cubic yards = 3,470 dump trucks

Data Collector
Brian Kling

Data Collection Date

Average Water Temperature

Location
Start: 41.34375799, -73.88064434
End: 41.34316927, -73.88088770

Survey Size
Area: 60.11 acres
Percent: 100.00% of waterbody
Volume: 751.91 acre ft

Est.Waterbody Volume ?
927462.05 cu. m
(751.91 acre ft)

Settings

Track Buffer:	100 m
Grid Cell Size:	7.0 m
Min.BV Detect:	5%
Min.Veg Depth Detect:	0.73 m

Offset Information
See Below

32.27 acre feet of sediment eliminated

$$\frac{751.91}{\text{acre feet}}$$

Lake Peekskill NY

Sediment Phosphorus content

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Date	6/20/18	6/20/18	6/20/18	6/20/18		10/22/18	10/22/18	10/22/18	10/22/18
Location	S1	S2	S3	S4		S1	S2	S3	S4
TOC mg/kg	72200	135000	181000	155000		90300	162000	208000	170000
P mg/kg	1230	1130	1110	775		995	1390	689	692

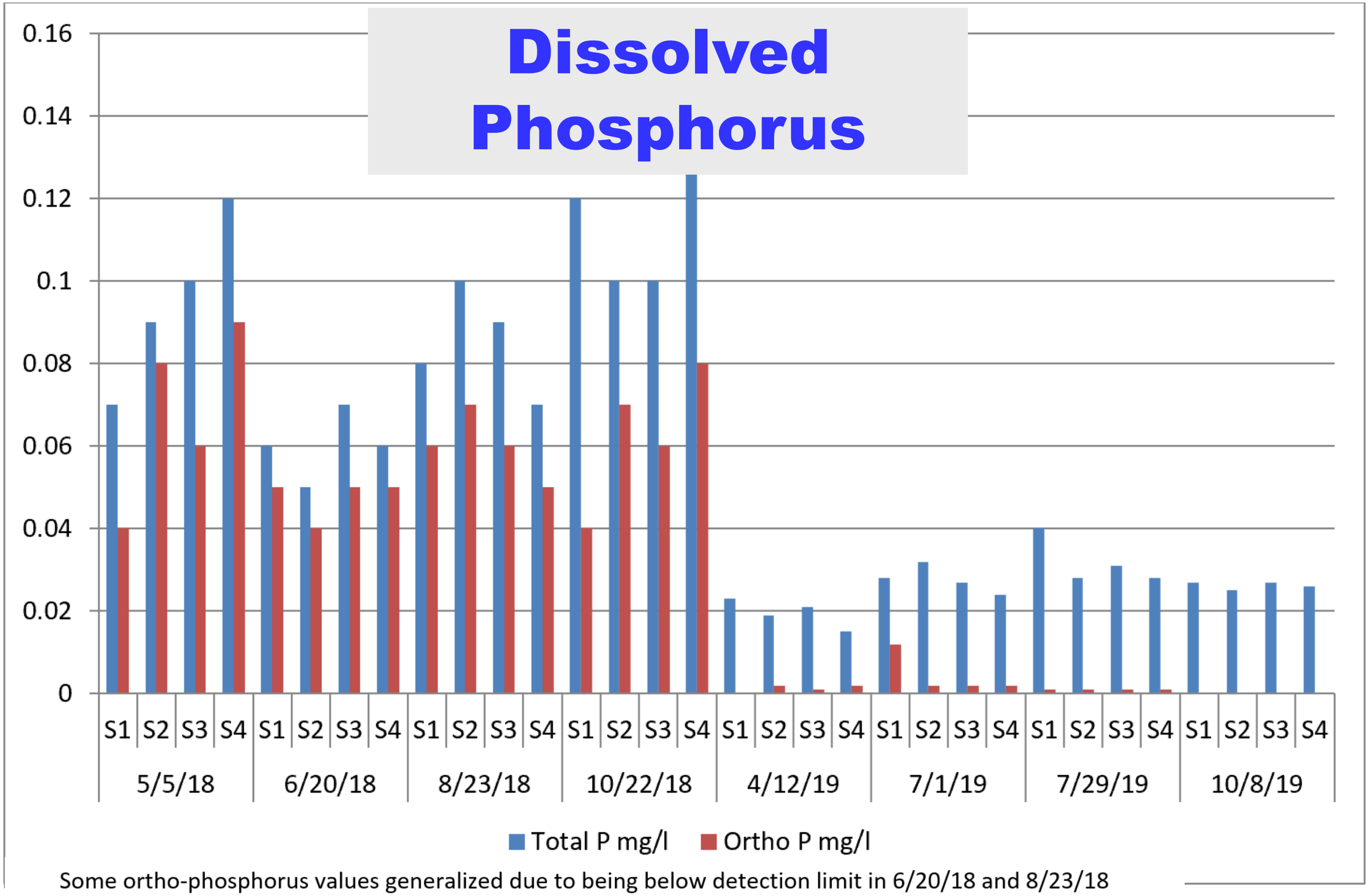
Mean P 1,061.25mg/l

Mean P 942.50mg/l

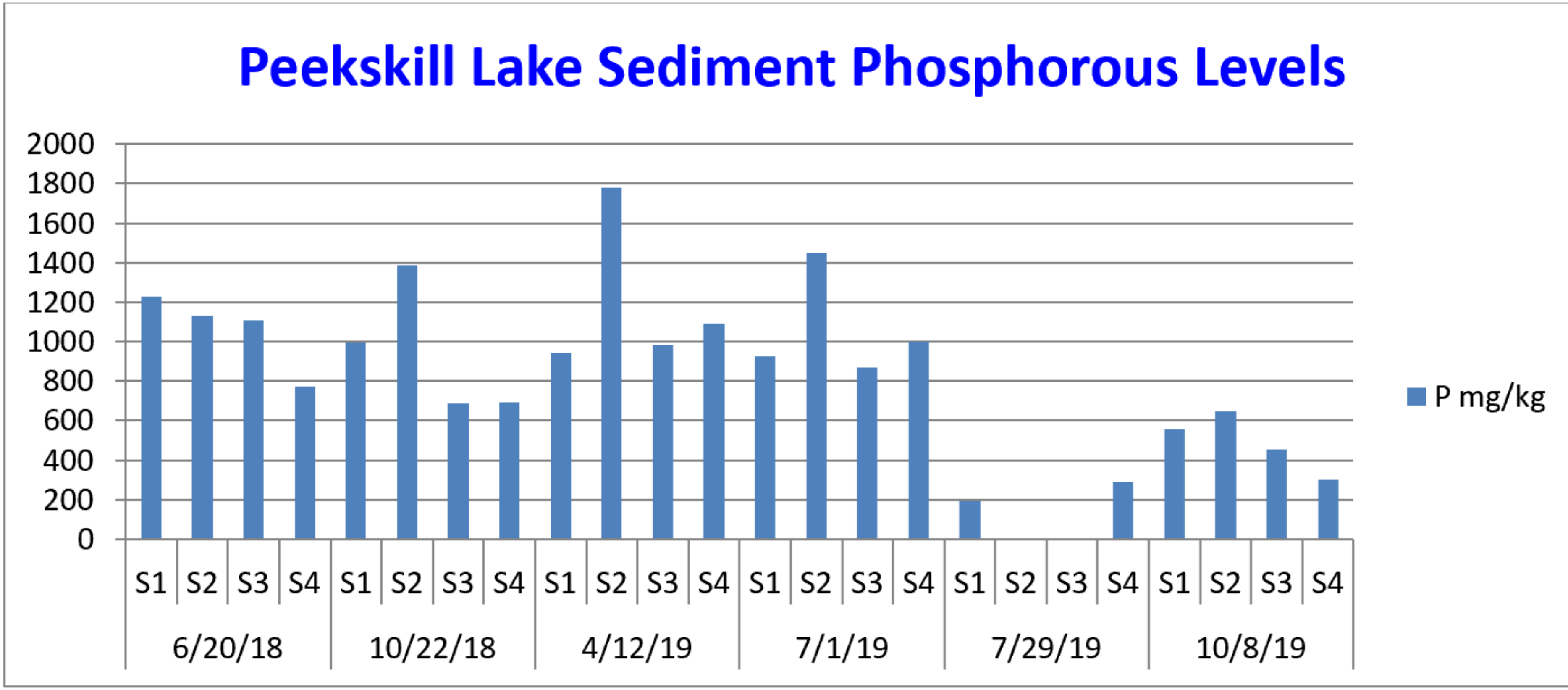
11% Reduction

Phosphorus concentration in remaining sediment has also been reduced

Dissolved Phosphorus



Some ortho-phosphorus values generalized due to being below detection limit in 6/20/18 and 8/23/18



Peekskill Lake Sediment Phosphorous Levels
2000
1800
1600
1400
1200
1000
800
600
400
200
0
S1 S2 S3 S4 S1 S2 S3 S4 S1 S2 S3 S4 S1 S2 S3 S4 S1 S2 S3 S4 S1 S2 S3 S4
6/20/18
10/22/18
4/12/19
7/1/19
7/29/19
10/8/19
P mg/kg

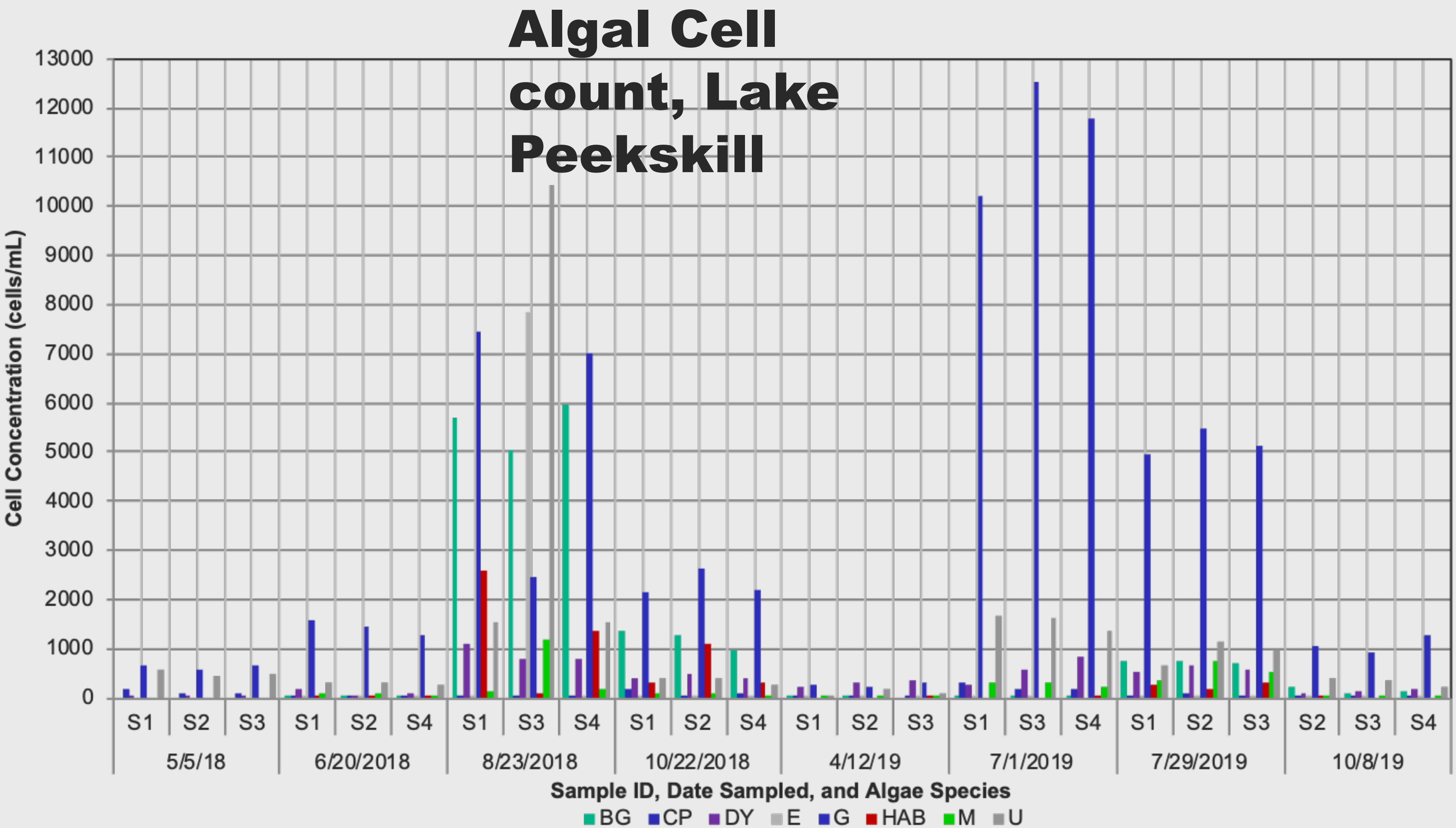
Sediment sampling showed there was over 1,000 mg/kg of phosphorus in the sediment when the Solution was commissioned.

If we assume the sediment weight before the system was started to be 1,000 kg/cubic meter, we end with the following equation:

37,917 m^3 sediment reduced x 1,000 kg/m^3 x 1,000 mg/kg = 37,917,000,000 mg P

37,917,000,000 mg P = 83,592.68 lbs.

This indicates that over 40 tons of phosphorus have been eliminated from the lake.


Algal Cell count, Lake Peekskill
Cell Concentration (cells/mL)
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
S1 S2 S3 S1 S2 S4 S1 S3 S4 S1 S2 S4 S1 S2 S3 S1 S3 S4 S1 S2 S3 S2 S3 S4
5/5/18
6/20/2018
8/23/2018
10/22/2018
4/12/19
7/1/2019
7/29/2019
10/8/19
Sample ID, Date Sampled, and Algae Species
BG CP DY E G HAB M U

Example #2

Roland Farm Lake VA

- 30 acres
- Max depth 16 feet initially
- Initial bathymetric scan in October 2017. Project started in April 2018.

Accumulated organic sediment shallowed out the lake and promoted invasive aquatic weed growth, setting up ideal conditions for future CyanoHABs. Emergent milfoil was everywhere that depth was less than 10 feet and you couldn’t launch a boat or get out to swim in the lake except at the dam wall.

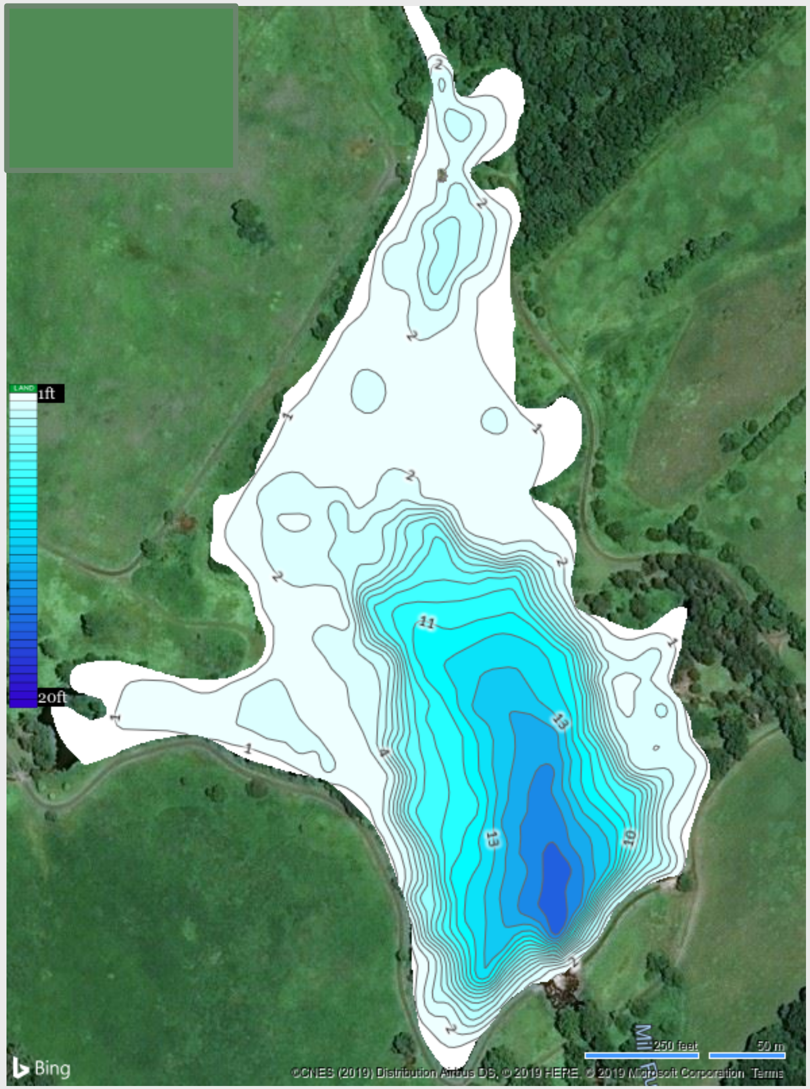
This is an example of pre-emptive action to prevent cyanoHABs from being able to establish themselves with the focus and emphasis on addressing total in-lake phosphorus. By digesting sediment the nutrient-rich rooting bed supporting invasive aquatic weed growth is eliminated, which when it dies off annually adds to the organic nutrient-rich sediment.

As a nutrient-rich sediment is formed, this allows rooted vegetation to grow which is a greater biomass that is generated and deposited back into the sediment when they die off. This retains a greater mass of nutrients in the water body and therefore increases the nutrient stockpile.

October 2017

Deepest Contour 16 feet

Deepest Reading <17 feet



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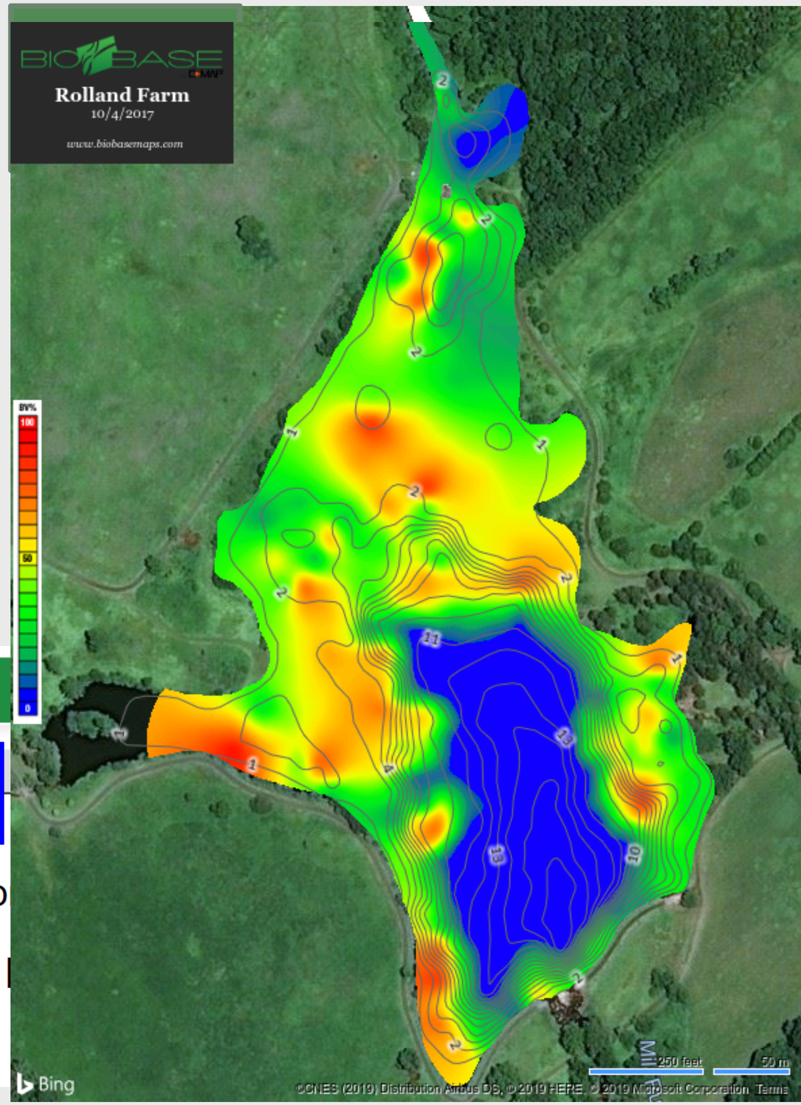
October 2017

2 feet contour in red



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Survey Summary

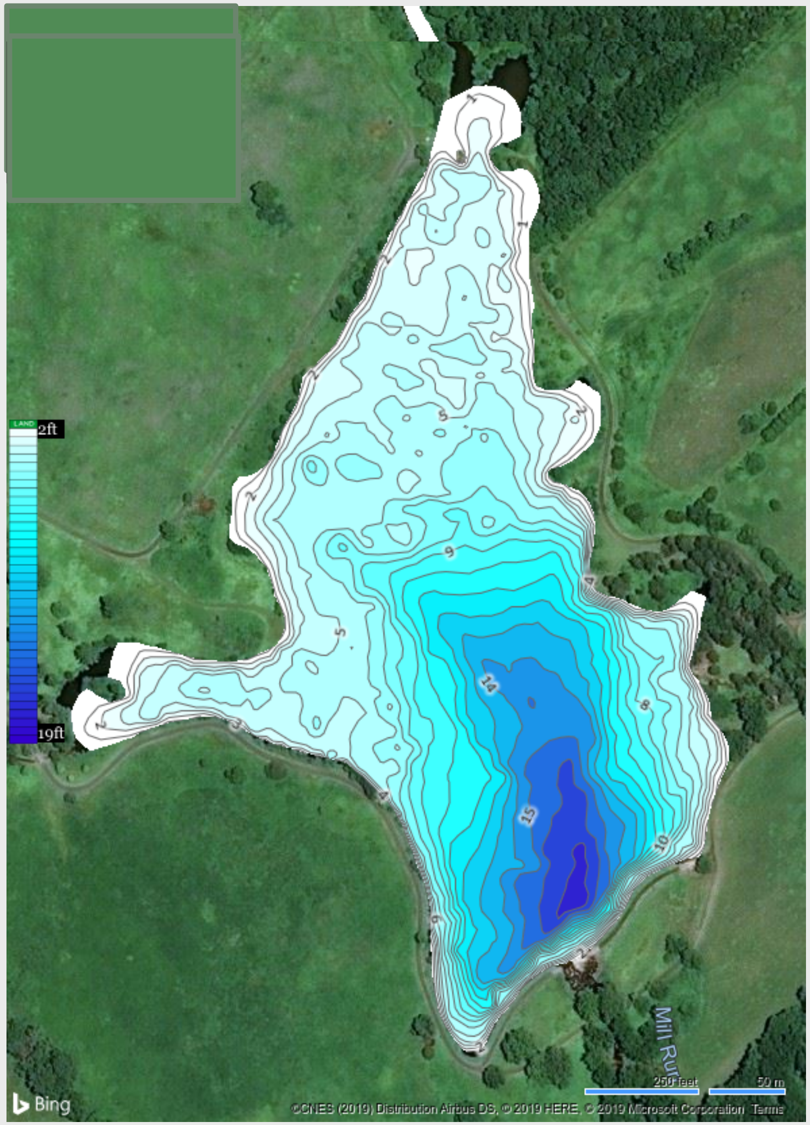
	Type	PAC	Avg BVp	Avg Depth	Distance	No.Points
Full	Point	32.9%	44.1%	8.25 ft	3.28 miles	2888

Figure 7- Biovolume percent fro

In October 2017, the average er volume taken up by aquatic vegetation was 44.1%.

aquatic vegetation.

<u>October 2017</u>
Deepest Contour 16 feet
Deepest Reading 18.52 feet
Ave Depth 4.95
Volume 150.69 acre-ft



<u>October 2019</u>
Deepest Contour 17 feet
Deepest Reading 18.59 feet
Ave Depth 7.08
Volume 215.71 acre-ft

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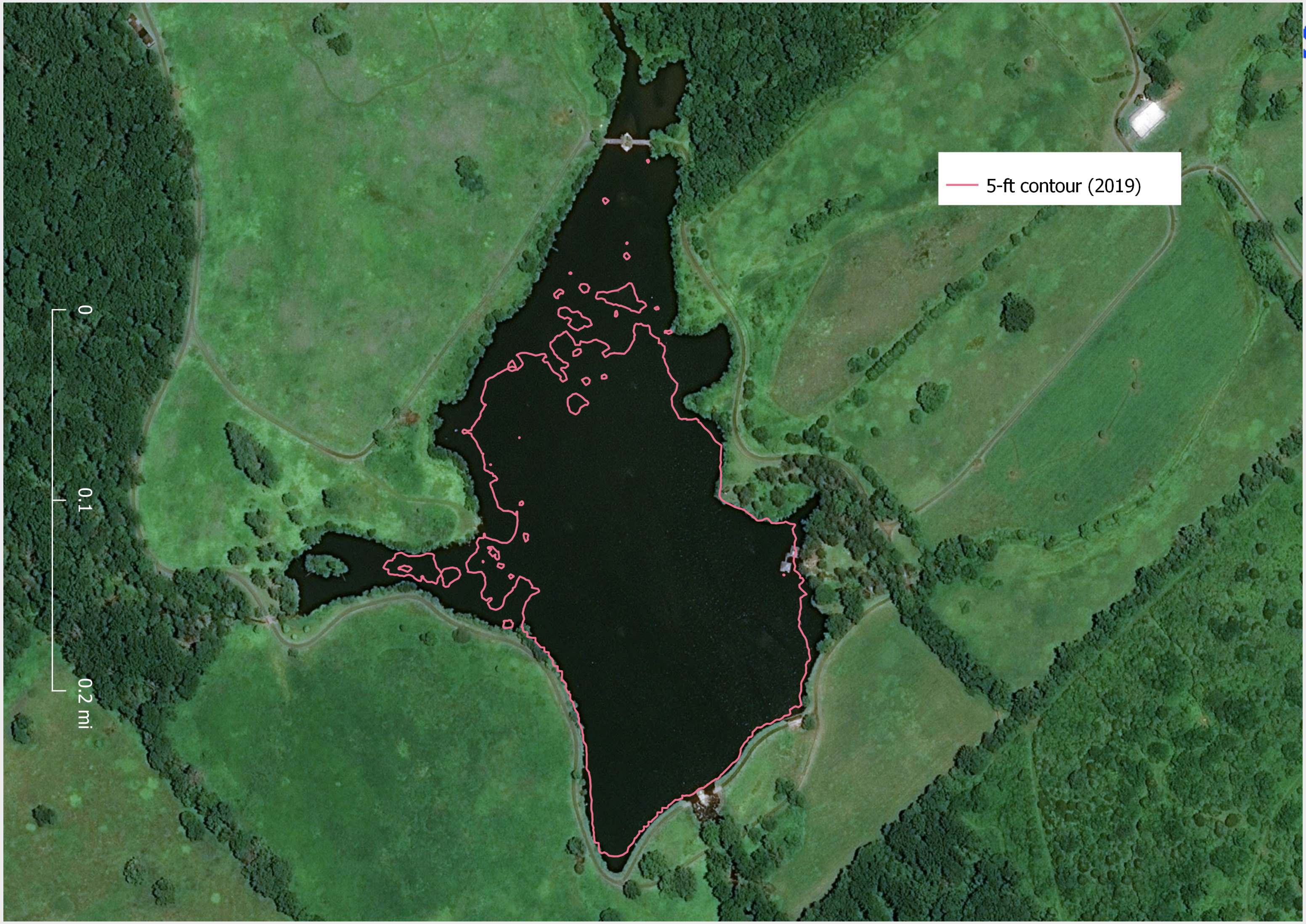
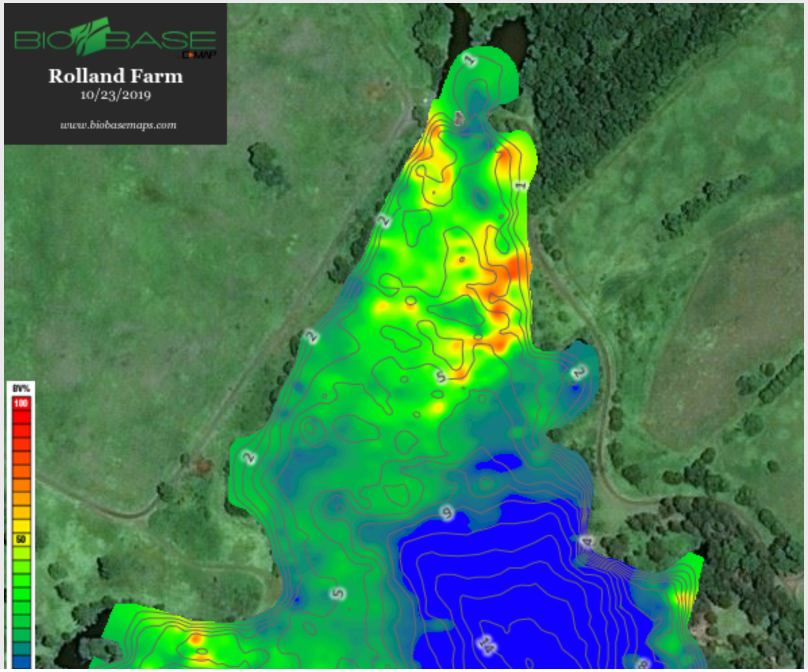

5-ft contour (2019)
0
0.1
0.2 mi



Survey Summary

	Type	PAC	Avg BVp	SD BVp	Avg BVw	SD BVw	Depth Range	Avg Depth	Distance	No.Points
Full	Point	54.1%	17.2%	±14.3%	9.3%	±12.0%	1.93 - 18.63 ft	8.75 ft	4.37 miles	3506

Figure 8. Biovolume percent from 2019 scan

In October 2019, the average biovolume percentage (Avg BVp) of the water volume taken up by aquatic vegetation was 17.2%.

Rolland Farm, Fauquier Virginia

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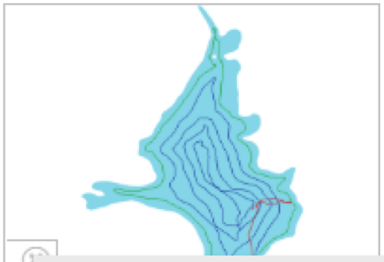
Waterbody Size: 30.45 acres

report link



Data Collector
Brian Kling

Data Collection Date
10/4/2017 2:23:24 PM (UTC)

Average Water Temperature
68.14° F

Location

Survey Size
Area: 30.33 acres
Percent: 99.60% of waterbody
Volume: 150.69 acre ft

Est.Waterbody Volume ?
186614.28 cu. m
(151.29 acre ft)

Settings

Offset Information
See Below

151.29 acre

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65.02 acre feet = 104,898 cubic yards

A dump truck holds 15 cubic yards

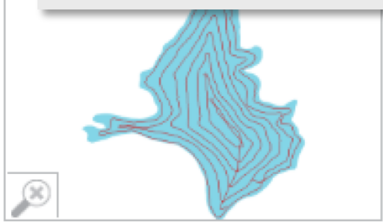
104,898 cubic yards = 6,993 dump trucks

Ro

Wat

4 PM (UTC)

report link



Data Collection Date
10/23/2019 2:54:36 PM (UTC)

Average
59.72° F

Location
Start:
End:

Volume: 215.71 acre ft

Est.Waterbody Volume ?

25 m
5.0 m
5%
0.73 m

65.02 acre feet of sediment eliminated

221.44 acre feet

Reviewer: McCormack, Ian
Comments: Inconsistent bottom tracking due to dense vegetation. - QQC

Summary:

1.Solution design followed by microporus aeration and bioaugmentation
2.Provides destratification and reoxygenation
3.Provides sediment digestion and movement of nutrients into beneficial components of the food web (i.e. not cyanoHABs)

- Increases the depth profile equating to a water volume increase – which equates to sediment volume decrease
- Reduction in P concentration in remaining sediment

4.Aeration is not a good method to reduce the volume of inorganic or lignin-rich organic sediments but is appropriate for cellulose-rich sediments (algae & soft-bodied submerged aquatic macrophyte plants). Biodegradable organic sediments are mostly generated within a lake and have increased over the last 100 years due to eutrophication. These sediments are susceptible to removal by aeration. This is the principal method in thousands of activated sludge waste treatment plants which oxidize the mass of human organic waste to CO_2 using fine air or oxygen bubbles and vigorous mixing.
5.These multilevel methods have been successful in other midwest lakes- i.e. Michigan, Pennsylvania, New York, Virginia

Acknowledgement: Lake result data-Dave Shackleton. www.SIS.bio

Key References

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- A Water Utility Manager's Guide to Cyanotoxins. 2015. American Water Works Association and Water Research Foundation. AWWA project #270; WRF project #4548.
- Managing Cyanotoxins in Drinking Water: A Technical Guidance Manual for Drinking Water Professionals. 2016. American Water Works Association; Water Research Foundation. Sept.
- Recommendations for Cyanobacteria and Cyanotoxin Monitoring in Recreational Waters. 2017. US-EPA Office of Water. EPA 820-R-17-001.
- Solutions for Managing Cyanobacterial Blooms: A scientific summary for policy makers. 2019. M.A. Burford et al. IOC/UNESCO, Paris (IOC/INF-1382).
- Toxic Cyanobacteria in Water: A Guide To Their Public Health Consequences, Monitoring and Management. 2nd Revised Edition. 2020 in press. World Health Organization.

Thank You – Questions??

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